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Partial Validation of Multibody Program to Optimize Simulated Trajectories II (POST II) Parachute Simulation With Interacting Forces

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Partial Validation of Multibody Program to Optimize Simulated Trajectories II (POST II) Parachute Simulation With Interacting Forces

1. Introduction

Flight simulation of entry bodies using a parachute is mathematically complicated and not easily characterized with traditional approaches. It involves multiple bodies, some of which are very flexible, flying in close proximity to each other with significant interaction effects. In past atmospheric entry missions, the parachute descent portion of the flight has been analyzed separately from the remainder of the trajectory, because the dynamics are so different from the rest of the entry. The goal of this work is to develop a multibody simulation of flight under a parachute that can easily be incorporated into a larger simulation of the entire entry, descent and landing (EDL) sequence. In this work the parachute is treated as a rigid body, however the interaction forces between the parachute and other rigid bodies are included.

This capability will provide the capability to create an end-to-end simulation from the last trajectory correction maneuver (TCM) before atmospheric entry to touchdown using the Program to Optimize Simulated Trajectories II (POST II). This simulation will provide attitude history predictions of all bodies throughout the flight. Issues such as recontact of jettisoned elements, design of parachute and attachment points, desirable line properties, and instrument coverage during parachute phase can be addressed using this simulation.

The Mars Pathfinder and Mars Polar Lander 6DOF simulations were done in ADAMS for the parachute portion of flight. Parachute drop test cases are developed using both MATLAB and POST II. The simulations are then verified by comparison of results.

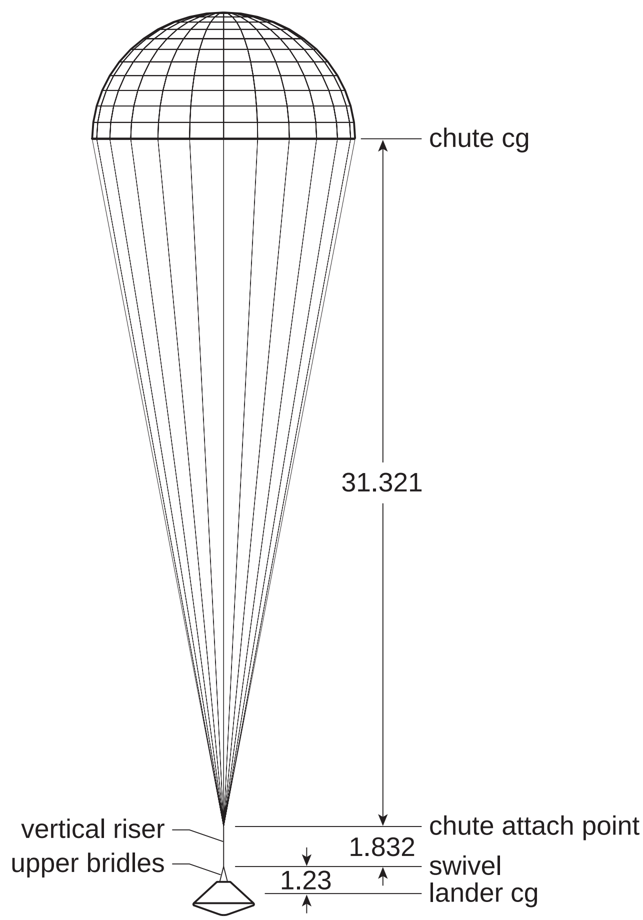


Figure 1 Vehicle entry configuration
Note: Dimensions are typical (not based on any specific Mars mission).

2. Approach

2.1. POST and POST II background information

The Program to Optimize Simulated Trajectories (POST) was originally written for the Shuttle program to find optimal ascent and entry trajectories. Over the years it has been steadily upgraded and improved to include many new capabilities. POST II is the latest major upgrade to POST. POST II relies on many of the technical elements established by POST, but has reworked the executive structure to take advantage of today's faster computers. The new executive routines allow POST II to simulate multiple bodies simultaneously, and to mix three degree of freedom (3DOF) with six degree of freedom (6DOF) bodies in a single simulation. In order to insure that POST II retains the high reliability and long heritage of POST, a battery of nearly 200 test cases has been developed and a source code control system has been implemented.

The new executive routines are written in C, while most of the force and moment calculations are in FORTRAN. For each vehicle in the simulation, the executive passes a structure containing all the information relevant to that vehicle into the dynamics portion of the code, where the forces and moments are calculated. In the current work, an additional subroutine was added that had access to the vehicle structures from all of the vehicles simultaneously and thus was able to calculate forces and moments between vehicles based on their relative positions, orientations, and translational and rotational velocities.

2.2. Modeling

The lines connecting the bodies are modeled as massless spring-dampers, except for the Descent Rate Limiter (DRL) which is described in section 3.2. The springs can be attached at any point on the body as defined by the user. No moments were applied except those due to force application away from the center of mass. Each line connects an attachment point on one body to an attachment point on another body and provides a tension-only force. In the stretched region, two different techniques have been used to model the behavior of the lines. In the first method, the spring force is proportional to the strain, and the damping force is proportional to the strain rate. In the nonlinear model, the line forces are not linearly proportional to the strain and the strain rate. The spring stiffness and damping coefficients are provided by the user as functions of strain and strain rate. In this model, the coefficients tend to be smaller at lower strains. Each of the spring-damper lines has an unstretched length and if the separation distance between the two attach-points is less than the unstretched length, the line tension is zero. Table 1 lists the linear line properties used. Nonlinear line properties are described in a later section.

In order to validate multibody POST II with interacting forces, a series of tests of increasing complexity are performed. These tests are intended to prove that the POST II model is implemented correctly by evaluating its performance on very simple problems that can be verified by other means. The first tests are simple drops from rest. Since these test cases have no off-axis forces, they can be modeled with a single degree of freedom for each body. For the period immediately after parachute deployment, the arrangement of bodies in flight is typically a single parachute, a swivel to allow rotation and the entry capsule supported by bridle lines (Figure 1). This entry configuration is common to most Mars entry missions such as the Viking, the Pathfinder, and the Mars Exploration Rover (MER, scheduled to launch in 2003). For the test cases discussed in this paper, this configuration is modeled using three bodies, the parachute, the entry capsule, and the swivel point. For the pathfinder and the MER missions, after the heatshield jettison, the lander is lowered from the backshell using a Descent Rate Limiter (DRL). The DRL is

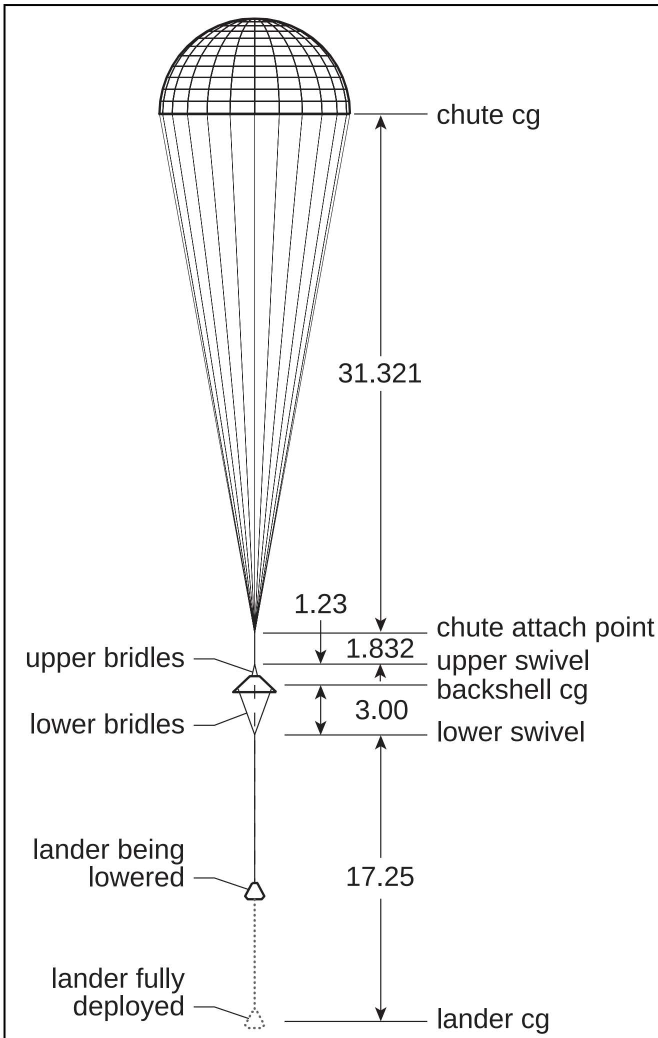


Figure 2 Vehicle entry configuration
Note: Dimensions are typical (not based on any specific Mars mission).

designed to control the descent rate by employing a centrifugal braking system. Once the DRL reaches its maximum length it is freed, allowing the lander to fall for a short distance until the lower vertical riser "catches" it. Test cases addressing the lander lowering are modeled with five bodies. Once the lander is fully deployed, geometry of the lines and attach points from the backshell to the parachute remain the same, however, the lander is now suspended from the backshell by the "lower bridles" and the "lower vertical riser" (Figure 2).

Table 1 Line properties

Line	Parameter	Value	
Upper vertical riser	L0	1.832	m
	K	60,000	N/m
	C	600	N/(m/s)
Upper bridles	L0	0.71524	m
	K	47,000	N/m
	C	470	N/(m/s)
Lower bridles	L0	2.92910	m
	K	47,000	N/m
	C	470	N/(m/s)
Lower vertical riser	L0	17.25	m
	K	60,000	N/m
	C	600	N/(m/s)

2.3. Test scenarios

There are several inputs parameters that are common to all test cases. A constant atmospheric density of 0.0135 kg/m^3 is assumed for all runs. Aerodynamic drag acts on the parachute only. Mars gravity and an oblate planet model have been used. All simulations start at zero latitude and zero longitude at a height of approximated 8.4 kilometers. Planet rotation is reduced greatly effectively making the planet non-rotating. Test cases fall under two different categories, three-body and five-body configurations. For all test cases in each configuration, all basic simulation parameters remain unchanged while initial conditions are varied to excite different vibrational modes. Tables 2 and 3 summarize the inputs used.

Table 2 Three-body configuration inputs

Body	Parameter	Value	
Parachute	DOF	6	
	Mass	16.0	kg
	Ixx	253.7	kg.m^2
	Iyy	1126.5	kg.m^2
	Izz	1126.5	kg.m^2
	Cd	0.46	
	Cp	1.57	m
	S_{ref}	178.47	m^2
Swivel	DOF	3	
	Mass	0.1539	kg
Backshell/lander	DOF	6	
	Mass	761	kg
	Ixx	238.02	kg.m^2
	Iyy	179.13	kg.m^2
	Izz	212.51	kg.m^2

Table 3 Five-body configuration inputs

Body	Parameter	Value	
Parachute	DOF	6	
	Mass	16.0	kg
	Ixx	253.7	kg.m^2
	Iyy	1126.5	kg.m^2
	Izz	1126.5	kg.m^2
	Cd	0.46	
	Cp	1.57	m
	S_{ref}	178.47	m^2
Upper Swivel	DOF	3	
	Mass	0.1539	kg
Backshell	DOF	6	
	Mass	177.0	kg
	Ixx	123.25	kg.m^2
	Iyy	70.43	kg.m^2
	Izz	83.34	kg.m^2
Lower Swivel	DOF	3	
	Mass	0.1539	kg
Lander	DOF	6	
	Mass	584.0	kg
	Ixx	77.53	kg.m^2
	Iyy	66.09	kg.m^2
	Izz	61.01	kg.m^2

The simplest test case is a simple vertical drop from rest with all lines taut but not stretched (Test Case 1a). The purpose of this test case is to verify that the equations of motions are being integrated consistently in POST II and MATLAB, and to create a baseline model where gravity and atmosphere models are established for subsequent analysis. In this test case, the forces acting on the bodies are not dynamic in nature; they simply increase steadily as the parachute velocity increases. Some important parameters, such as final altitude and velocity, were compared at the end of the simulation, and the results showed very good agreement.

The next test starts with a one-centimeter slack in the Vertical Riser (Test Case 2a). In this test case, as the bodies are dropped, the lines become taut and vibrational dynamics are introduced. This test case was repeated for linear and nonlinear line properties (Test Case 2b).

In test case 3, all bodies start from rest except for the entry capsule which is given an initial horizontal velocity of 1 m/s. The bodies go through a pendulum-like motion as they descend. There is more dynamical motion in test case compared to test cases 2a and 2b, and body motions are not restricted to one degree of freedom per body. Due to the added degrees of freedom, the simplified MATLAB simulation is no longer used. The results of this test case will be discussed in a subsequent report.

Test Cases 4a thought 4e simulate the motion of the five-body configuration. In these cases, it is assumed that the lander is fully deployed and the dynamics caused by the deployment mechanism have damped out. These test cases are designed to incrementally increase the dynamics of the five-body configuration by changing the initial conditions. Again these simulations are beyond the capabilities of the MATLAB simulation.

Test case 5 simulates the deployment of the lander using the DRL. It is assumed that all bodies are initially moving vertically downward close to the terminal velocity of the system. In this test case, motions of all bodies are in the vertical direction; therefore the MATLAB simulation could be used.

Test cases 6a through 6d investigate the effects of wind gusts on the bodies. Again, these test cases cannot be done using the MATLAB simulation.

Test case 7a simulates the deployment and opening of the parachute. The deployment is assumed to occur vertically; therefore the MATLAB program can simulate the motions. In this test case the entry capsule is moving vertically downward at a rate of 500 m/s. The parachute is then given an instantaneous velocity of 70 m/s backward with respect to the entry capsule. The parachute opening is initiated when the lines connecting the parachute to the entry capsule reach their free length.

For test cases 2a and 2b, POST II CPU run times were recorded and compared. The CPU run times and stability of the simulations were highly sensitive to time step and the swivel mass. Table 4 is an outline of all the test cases set up to verify POST II multibody modeling with interacting forces. Note that only the results from test cases 2a, 2b, 5a, and 7a are presented in this document.

Table 4 Test case outline

case #	**description**	
1	Vertical drop from rest, all lines initially taut	
	1a	POST II vs. MATLAB
	1b	POST II vs. ADAMS
2	Vertical drop from rest, one centimeter slack on the vertical riser	
	2a	POST II vs. MATLAB,
	2b	POST II vs. MATLAB, nonlinear line properties
	2c	POST II vs. ADAMS,
3	Drop from rest, entry capsule with 1 m/s initial horizontal velocity	
	3a	POST II vs. ADAMS
4	Fully deployed five-body configuration (all POST II vs. ADAMS comparisons, IC: Initial Conditions)	
	4a	IC: Lander 1 m/s N, lines at free length, vertical velocity = 0
	4b	IC: Backshell 1 m/s N, lines at free length, vertical velocity = 0
	4c	IC: Backshell 1 m/s N, Lander 1 m/s N, lines at free length, initial velocity = 0
	4d	IC: Chute 1 m/s N, Backshell 1 m/s E, Lander 1 m/s N, lines at free length, vertical velocity = 0
	4e	IC: Chute 1 m/s N, Backshell 1 m/s E, Lander 1 m/s N, lines at equilibrium, vertical velocity ~ 72

5	Lander deployment (lowering line)	
	5a	POST II vs. MATLAB
	5b	POST II vs. ADAMS
6	Fully deployed five-body configuration with gusts, lines initially at equilibrium (all POST II vs. ADAMS)	
	6a	Constant density atmosphere with one square wave wind gust (N), aero on chute only, -90 fpa
	6b	Constant density atmosphere with two square wave wind gusts (N and E), aero on chute only, -90 fpa
	6c	Realistic atmosphere with two square wave wind gusts (N and E), aero on chute only, -90 fpa
	6d	Realistic atmosphere with two square wave wind gusts (N and E), aero on all bodies, -90 fpa
7	Chute deployment	
	7a	POST II vs. MATLAB, -90 fpa
	7b	POST II vs. ADAMS, -90 fpa
	7c	POST II vs. ADAMS, -60 fpa

3. Results

For test cases 2a, 2b, 5a, and 7a, since the motion is primarily in the axial direction, every body effectively has one degree of freedom. This equates to three degrees of freedom for test cases 2a, 2b and 7a, and five for test case 5a. Simple spring-damper MATLAB models have been constructed for comparison. By using the same inputs for both POST II and MATLAB, good comparisons can be obtained between the simulations. In the POST II simulation, three lines run independently between the upper swivel point and the lander. In the MATLAB simulation, an equivalent spring in the axial direction is used. For each test case, plots are presented to show how a few important simulation parameters compare. The plots are provided in pairs. The first of each pair shows the comparison for the entire sixty seconds, and the second shows the first two seconds. The plot for each figure is supplied with a percent difference plot on the bottom to see how well the simulations matched.

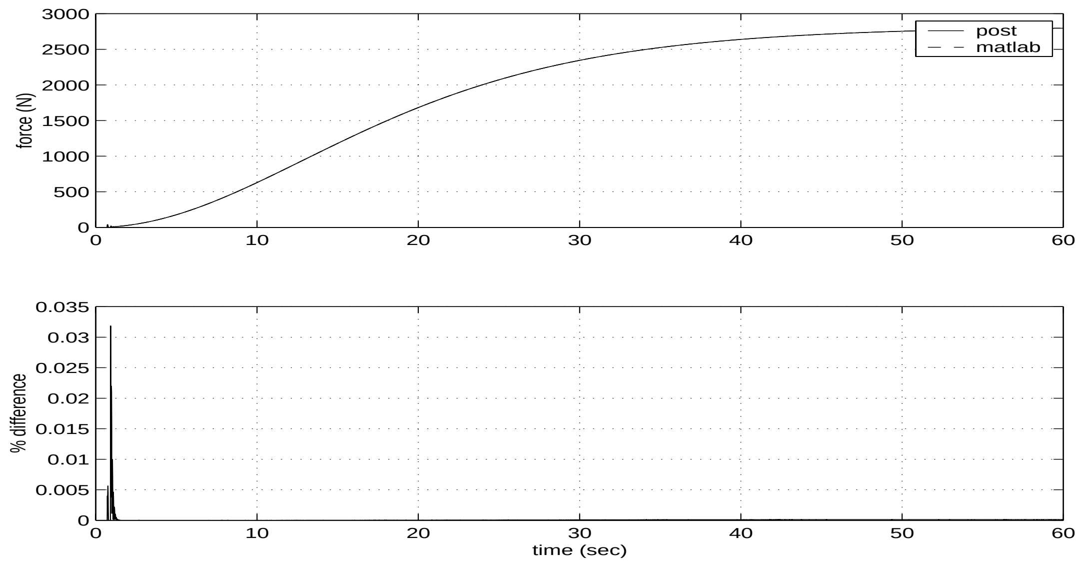
3.1. Test case 2

In this "vertical drop" test case, all bodies start from rest. To introduce some dynamics into the simulations we included a slack of one centimeter in Vertical Riser. Note that the aerodynamic drag acts on the parachute only. So, the entry capsule initially drops faster than the parachute. Eventually, the Vertical Riser runs out of slack, thus exciting the system. This simulation has been analyzed using two different line properties in tension.

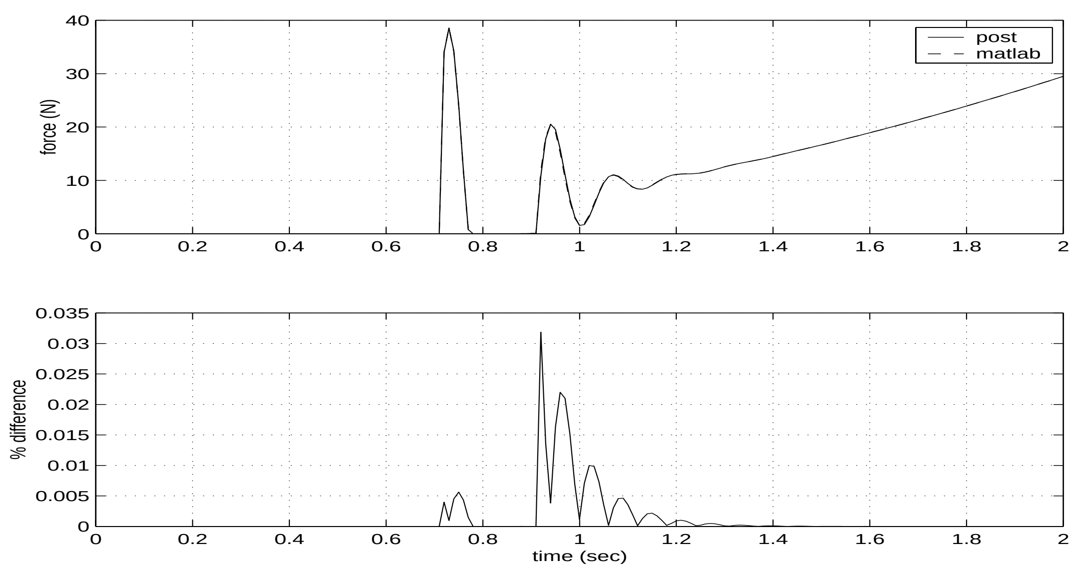
3.2.1. Test case 2a – Three-Body with linear lines

In this simulation, the lines have linear stiffness and damping properties while in tension. Figure 3a is sum of line forces on the parachute. The Vertical Riser is the only line exerting force on the parachute. Note that the simulation started with a one-centimeter slack in the Vertical Riser. It takes about 0.7 second for the slack to run out. The line then undergoes an oscillatory motion. The oscillations damp out approximately 0.5 second after they started (Figure 3b). After this point, the line force gradually builds up until it reaches a steady state value.

Figure 3 Net line force on the parachute (POST II vs. MATLAB)



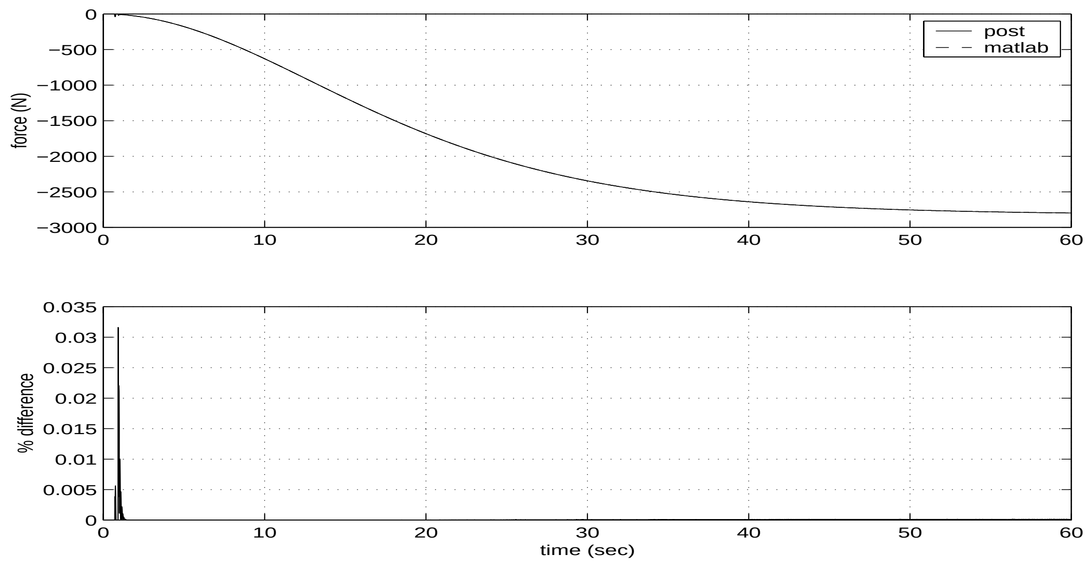
3a Entire simulations



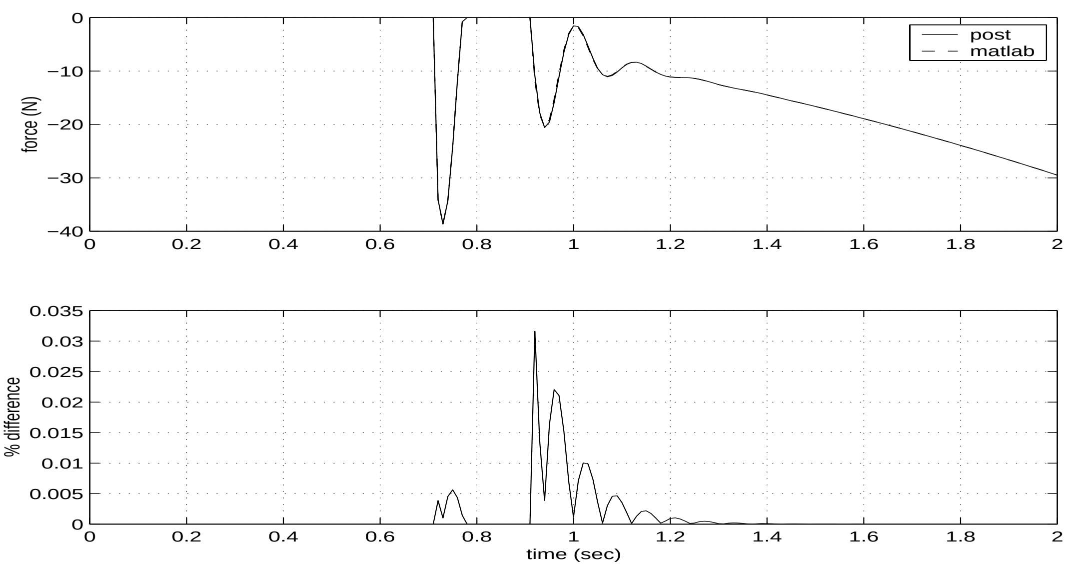
3b Initial two seconds

Figures 4a and 4b show sum of line forces on the entry capsule. The forces in these figures are equal in magnitude but opposite in direction compared with Figures 3a and 3b. This difference is because the swivel mass is small, thus producing small inertial forces.

Figure 4 Net line force on the entry capsule (POST II vs. MATLAB)



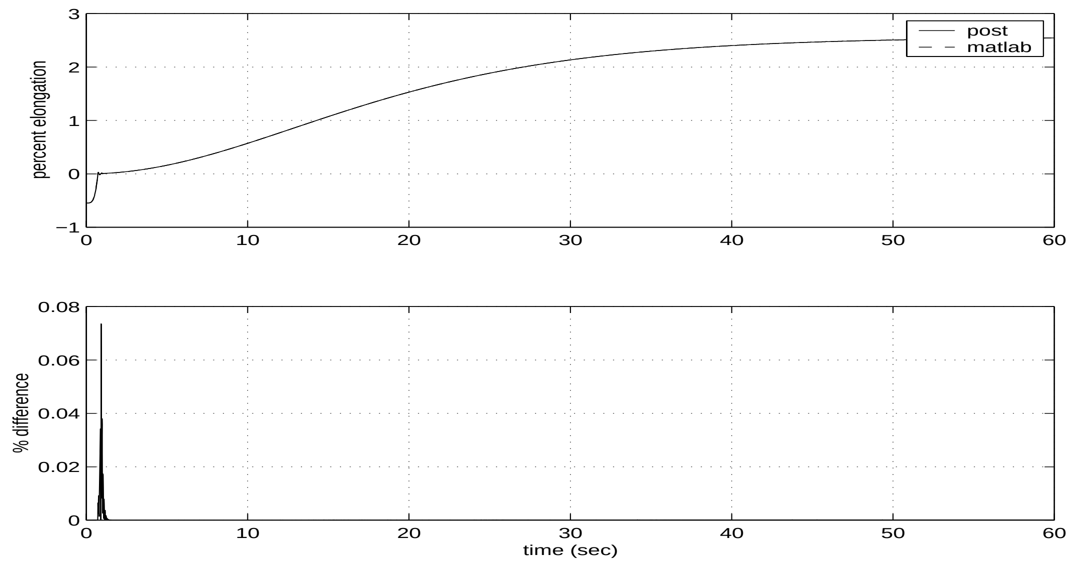
4a Entire simulation



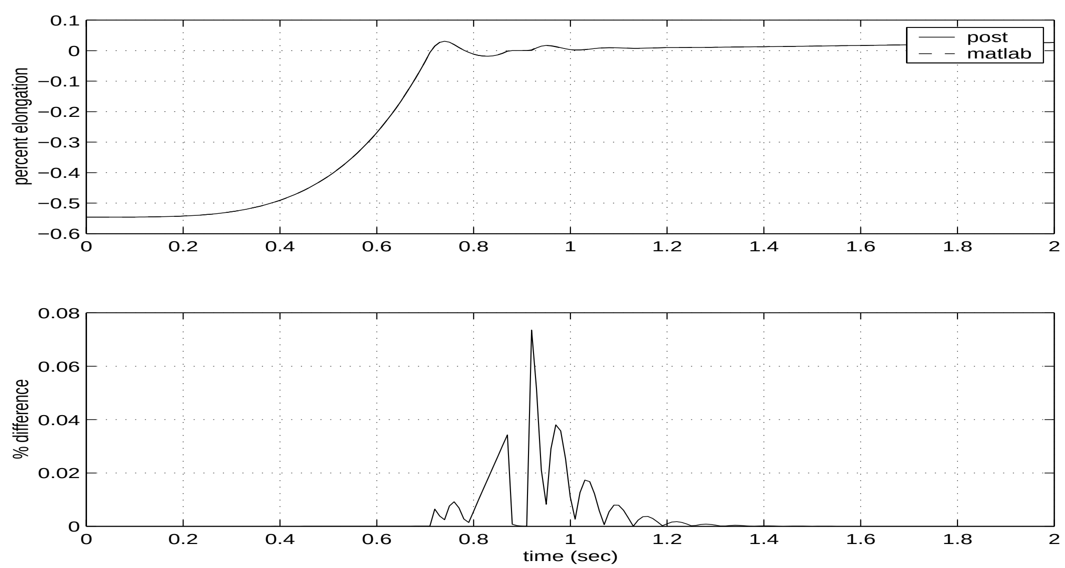
4b Initial two seconds

Figures 5a and 5b show the Vertical Riser percent elongation. Negative numbers indicate slack in the line. Recall that the simulation started with a slack of one centimeter in the Vertical Riser. It takes about 0.7 second for the slack to run out (Figure 5b). After a few oscillations, dynamics damp out and the Vertical Riser stays taut for the remainder of the simulation.

Figure 5 Vertical riser percent elongation (POST II vs. MATLAB)



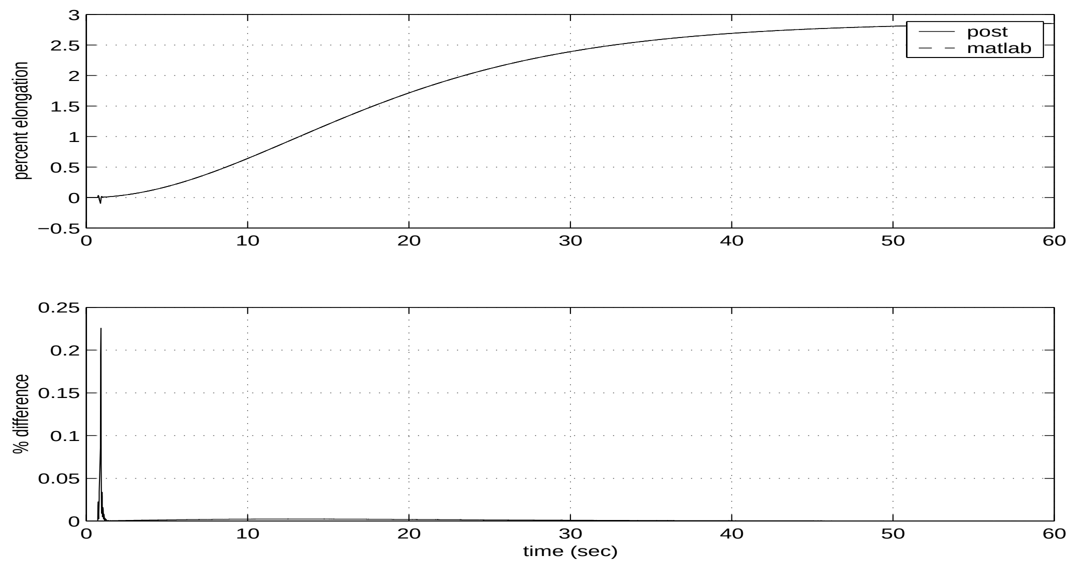
5a Entire simulation



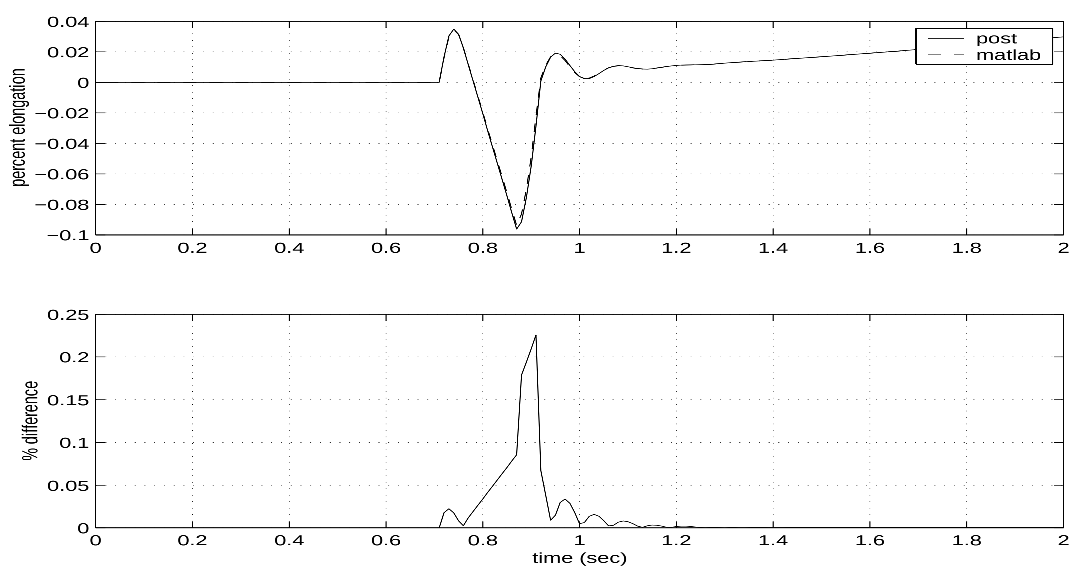
5b Initial two seconds

The simulation started with no slack in the Upper Bridle lines. This continues to be the case until 0.7 second into the simulation. At this point the Vertical riser runs out of slack (Figure 6b), which in turn introduces dynamics into the entire systems. Figures 6a and 6b show the elongation history of a single Upper Bridle line.

Figure 6 Upper bridle percent elongation (POST II vs. MATLAB)



6a Entire simulation



6b Initial two seconds

3.2.1. Test case 2b – Three-Body with nonlinear lines

Using linear line properties can lead to numerical problems in the simulations. The line forces at the start of simulation have spikes (Figure 3b). These spikes are caused when the lines switch back and forth from slack to taut. This effect can be overcome by using a very small time step (0.0001 sec), but the reduction in time step leads to large run times. In this section we will investigate using lines with nonlinear stiffness and damping properties. Non-linear line properties tend to have a stabilizing effect on the simulation, thus enabling us to use larger time steps. The line properties chosen for this analysis are taken from the Viking mission. Figures 7 and 8 show the Viking line properties from Reference 1.

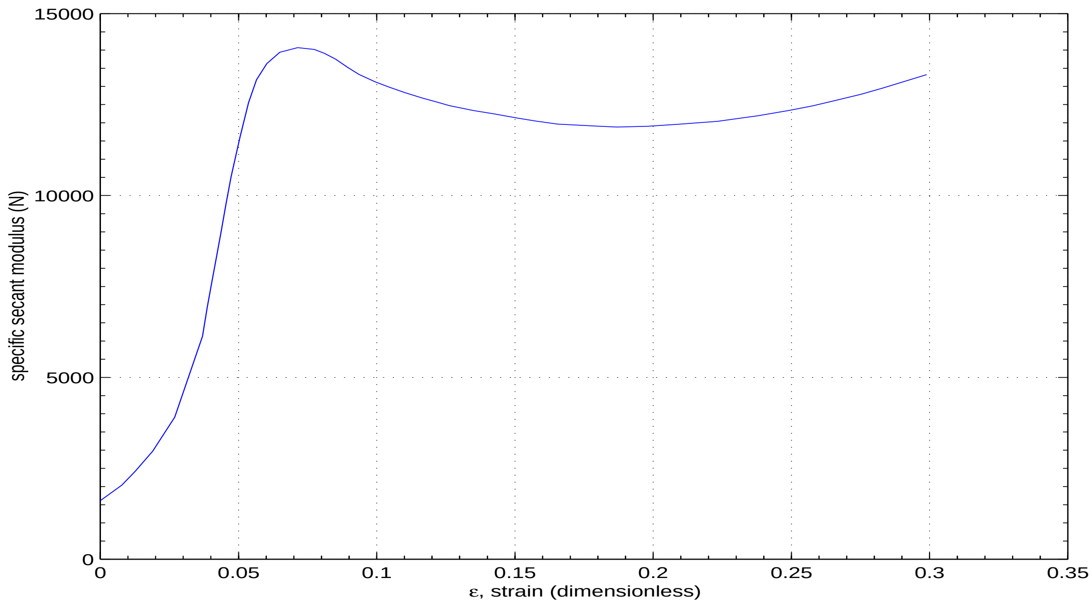


Figure 7 Line stiffness

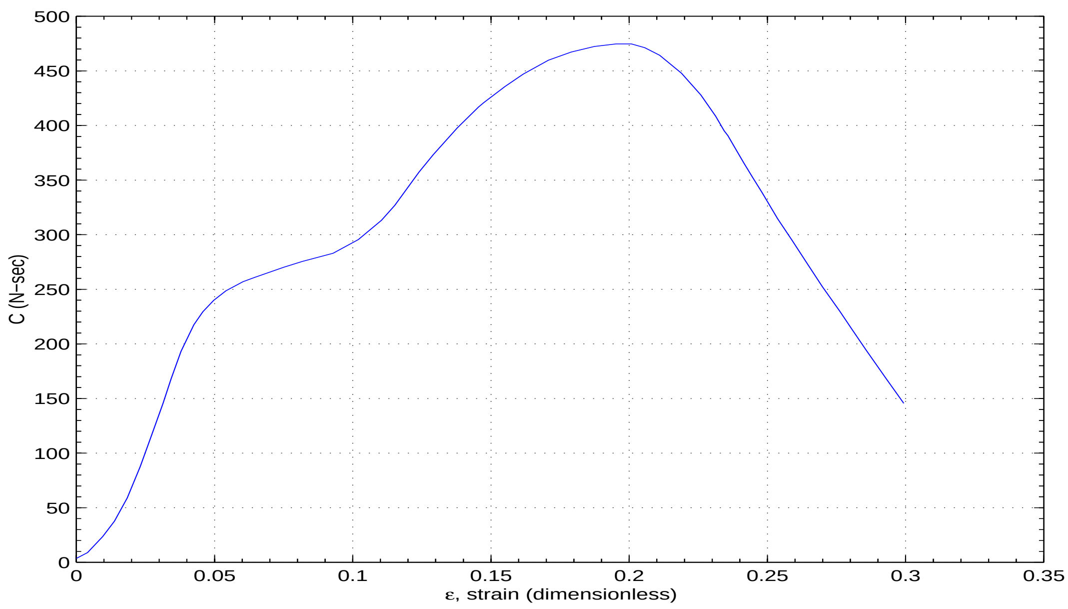


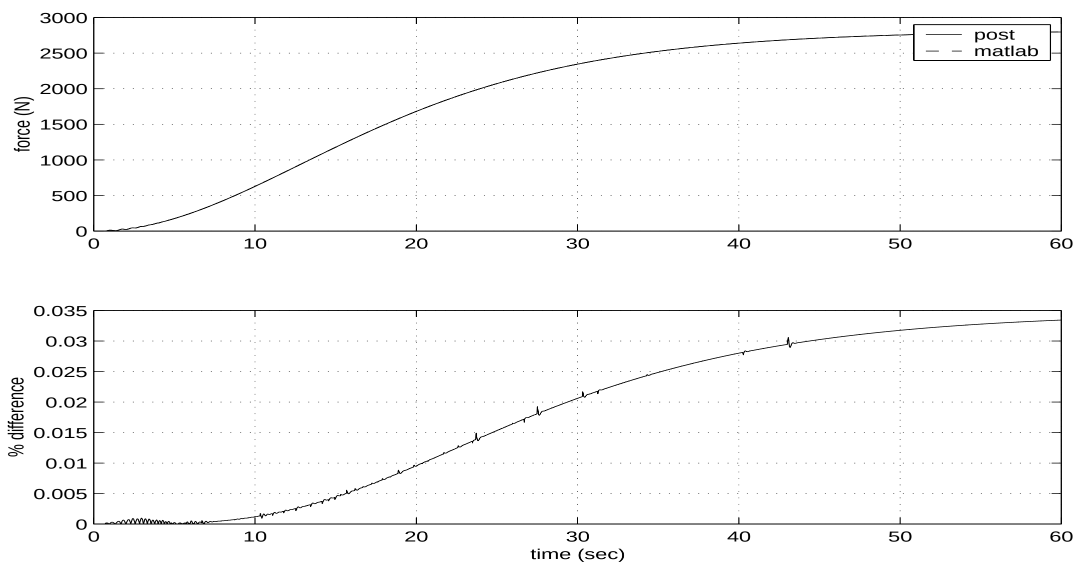
Figure 8 Line damping

Again a slack of one centimeter is introduced to the system at the start of the simulation. This will induce some dynamics into the system, causing oscillations that damp out after a few cycles. In this analysis we also examined the effect of changing the integration time step. This simulation is more stable, allowing us to use larger time steps. However to use larger time steps successfully we had to slightly increase the swivel mass (from 0.15 to 0.5 Kg). Both POST II and MATLAB showed the same behavior in this regard. The following plots are the results of the POST II and MATLAB simulations, with all inputs same as before except for the line properties. The actual mass of the swivel is currently unknown. In addition, since all the lines are modeled as massless spring-dampers, some of their mass could be added to the swivel mass. An appropriate value for the swivel mass will be determined for mission simulations.

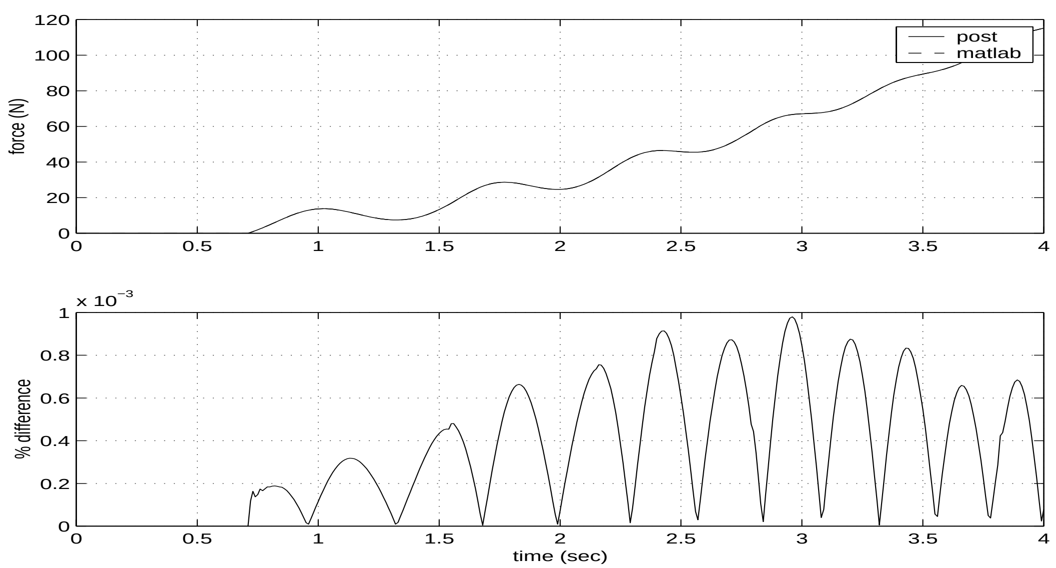
The following plots show the comparison between MATLAB and POST II. Overall, the simulations showed very good agreement.

Figure 9a is sum of line forces on the parachute with nonlinear line properties. Note that transition from slack to taut in this model is a lot smoother (Figure 9b). There are no abrupt changes in force as compared with the linear model (Figures 3a & 3b).

Figure 9 Net line force on the parachute (POST II vs. MATLAB)



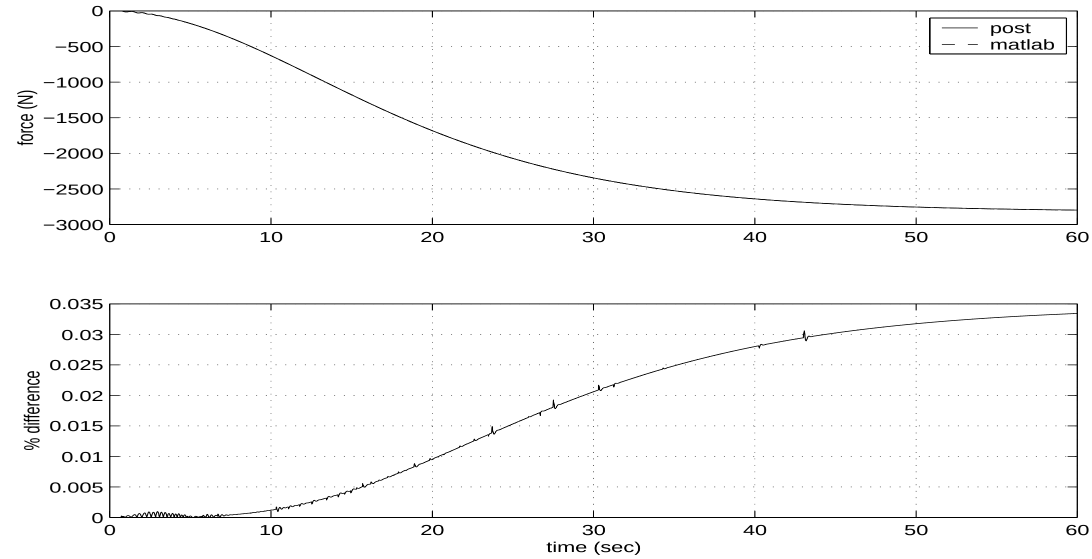
9a Entire simulation



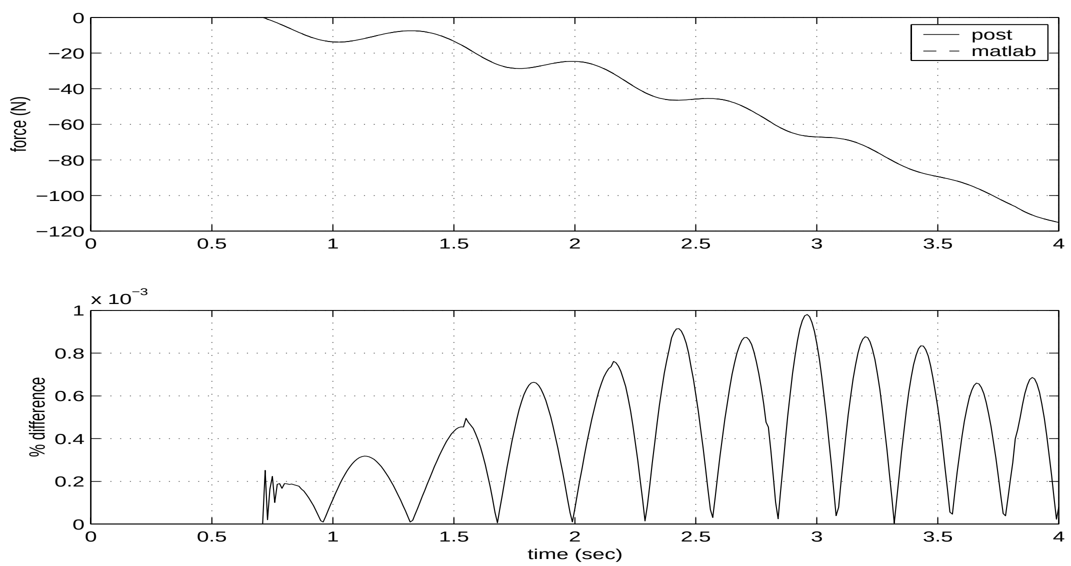
9b Initial four seconds

Figures 10 and 10b show sum of line forces on the entry capsule. The forces in these figures are equal in magnitude but opposite in direction compared with Figures 3a and 3b.

Figure 10 Net line force on the entry capsule (POST II vs. MATLAB)



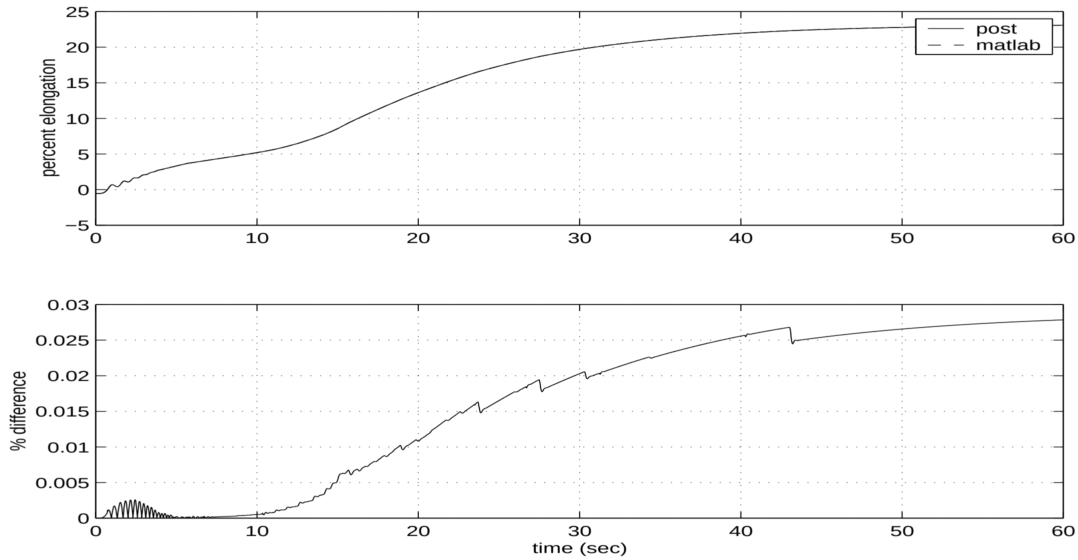
10a Entire simulation



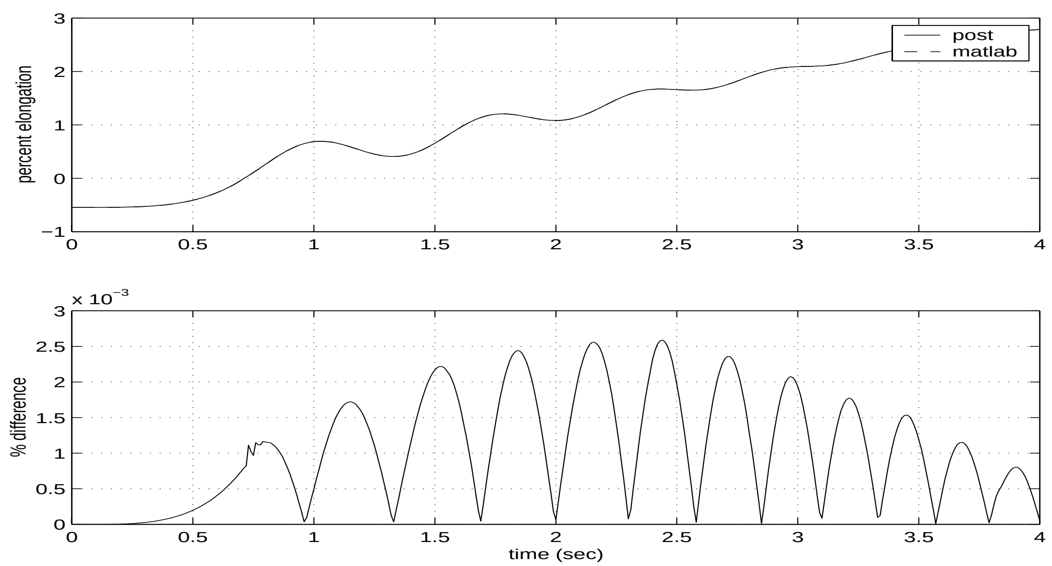
10b Initial four seconds

Figures 11a and 11b show the Vertical Riser percent elongation. Negative numbers indicate slack in the line. Recall that the simulation started with a slack of one centimeter in the Vertical Riser. It takes about 0.7 second for the slack to run out (Figure 11b). The line goes into tension and stays in tension for the remainder of the simulation.

Figure 11 Vertical riser percent elongation (POST II vs. MATLAB)



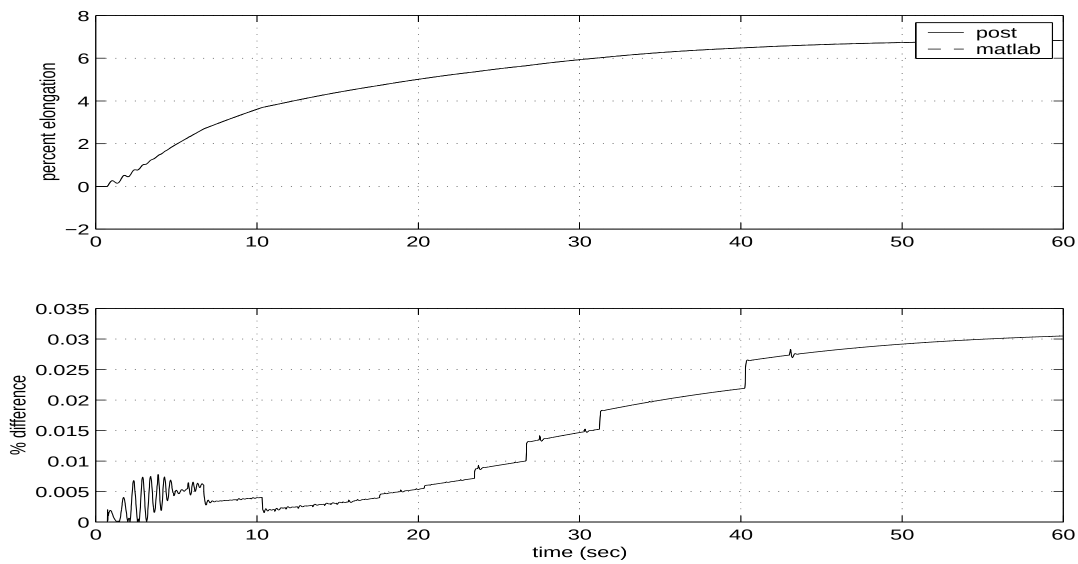
11a Entire simulation



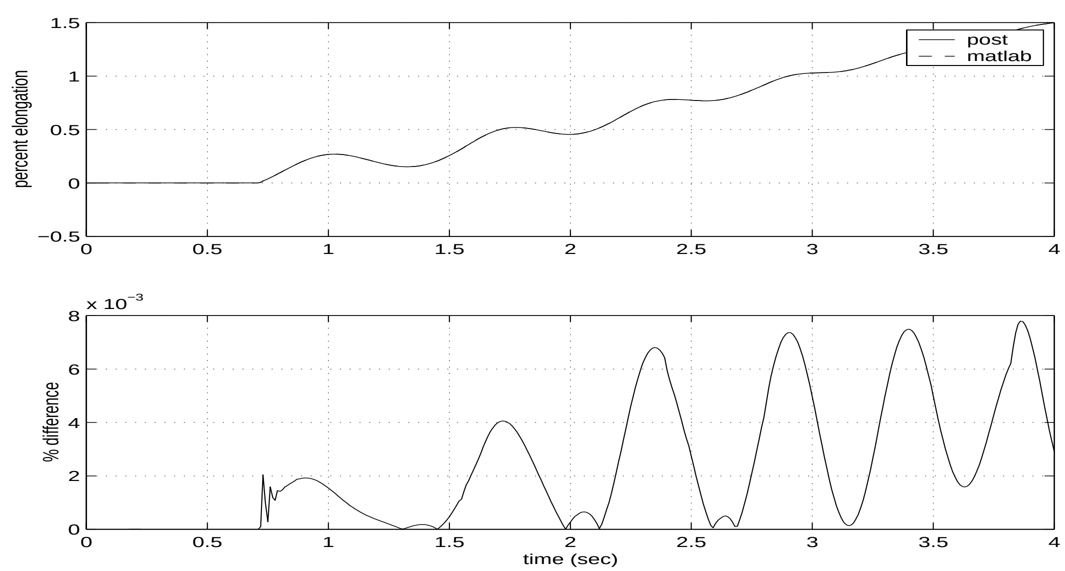
11b Initial four seonds

The Upper Bridle lines had no slack at the start of the simulation. After about 0.7 second the Vertical Riser runs out of slack and the resultant forces are transferred to the Upper Bridle lines. Figures 12a and 12b show the elongation history of a single Upper Bridle line.

Figure 12 Upper bridle percent elongation (POST II vs. MATLAB)



12a Entire simulation



12b Initial four seconds

3.2. Test case 5a – Descent Rate Limiter

Airbag based landing systems, such as those used for Mars Pathfinder and MER, require a lander to be lowered from the entry body backshell while still attached by a line. To reduce the dynamic effects of this lowering maneuver, a descent rate limiter (DRL) is used to control the rate of descent of the lander relative to the backshell. The DRL is located inside the lander and is attached to the backshell by the DRL line. The line is cut once it reaches full length at the end of the lowering maneuver. The lander then goes into free fall for a short distance. There is a second triple bridle and vertical riser below the backshell to support the lander at the end of the fall.

The DRL used for Pathfinder was based on friction in a rotating spool. The damping force provided by this type of mechanism is proportional to the square of the velocity of separation. In this case, the damping force is given by: $\mathrm{F} = \dfrac{\mathrm{c}\dot{\mathrm{d}}}{\mathrm{R}^3(\mathrm{d})}$ where $R(d) = R_0 \sqrt{1 - \left(1 - \dfrac{R_1^2}{R_0^2}\right)\dfrac{d-s}{L-s}}$ as described in (Reference 2). Here F is the damping force, c is a mechanical constant related to the mechanism design, R is the drum radius, d is the distance from the backshell attachment to the lander, $\dot{\mathrm{d}}$ is the descent rate, L is the length of the DRL tape, s is the initial slack in the line, R_0 is the initial radius of the drum and R_1 is the final radius of the drum. The values of the input parameters used in this test case are listed in Table 5. A swivel point is modeled below the backshell exactly similar to the swivel point above the backshell. For a vertical drop, this is again a one degree-of-freedom per body system.

This model was implemented in POST II and in MATLAB. For this simulation, all bodies were initially falling at 71 m/s, which is approximately the terminal descent rate experienced in case 2. The lander and backshell are assumed to have coincident centers of gravity and identical velocities initially. Lines were assumed linear with properties the same as those in the upper lines. Because the backshell is attached to the parachute (via the upper swivel), the lander will accelerate away from the backshell until the DRL slows the motion to a steady descent rate.

The net line force on the lander is shown in Figure 13. The force in the DRL line quickly reaches an approximately constant value which is held until the length of line is exceeded. Then the lander drops until it is caught by the lower vertical line. Because of the dynamics of the DRL, this constant force does not result in a constant separation rate, because the radius of the tape around the drum roll is not constant. The descent rate of the lander relative to the backshell is shown in Figure 14. Overall, the agreement between the MATLAB and POST II simulations is very good. Slight numerical differences between the two simulations causes the lander to fall off of the DRL and be “caught” by the lower vertical at slightly different times. When the lander is caught by the lower vertical line, the line force goes from zero to a large value very quickly. If the two simulations are not synchronized, this rapid change will results in a relatively large percentage difference in the line forces for a few time steps (spikes in Figure 13).

Table 5 DRL input parameters

Input Parameter	**Value**
R_0	0.044 m
R_1	0.012672 m
c	0.001 N-m-sec^2
s	0.00 m
L	20.00 m

Figure 13 Net line force on the Lander (POST II vs. MATLAB)

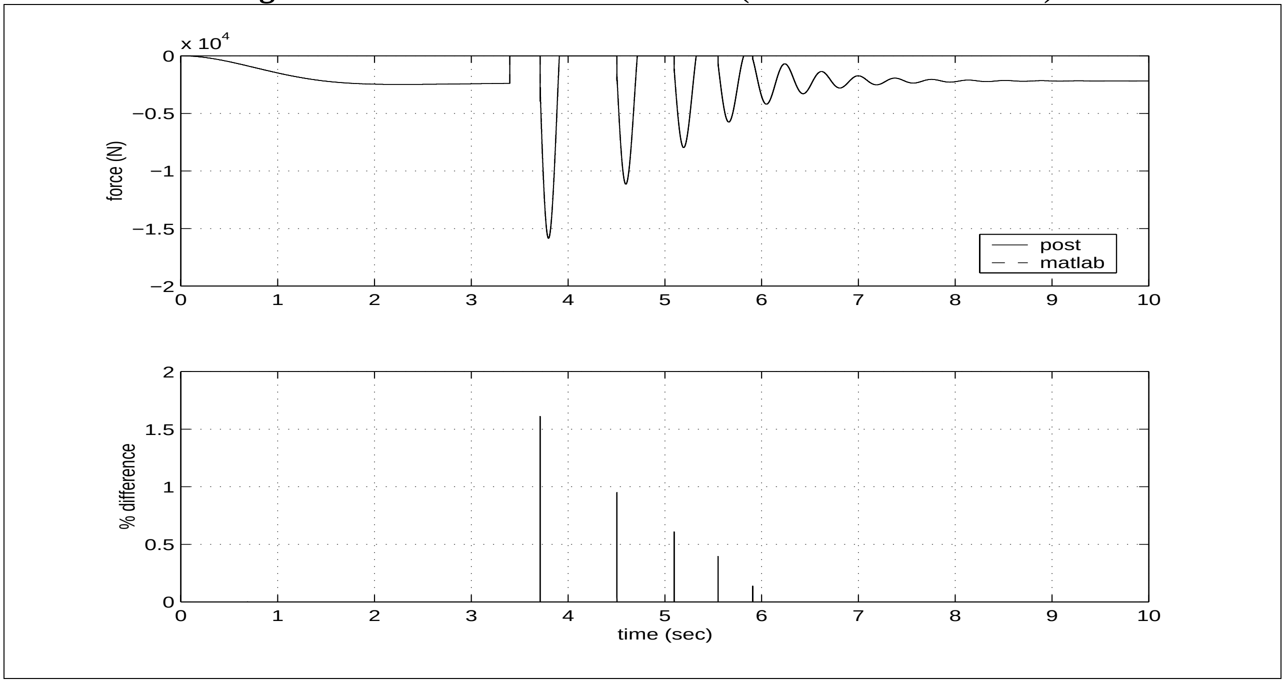
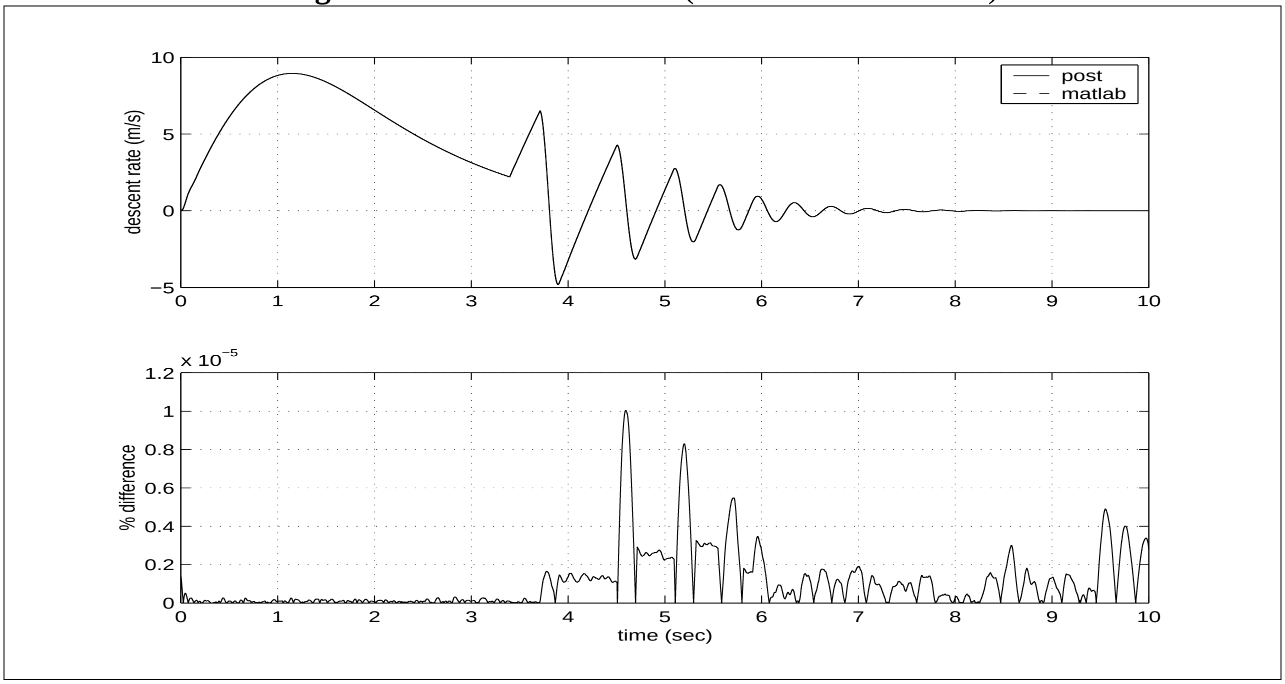


Figure 14 Lander descent rate (POST II vs. MATLAB)



3.3. Test case 7a – Parachute Deployment

This test case begins when the parachute is ejected from the back of the entry capsule by the ejection mortar. Test case 7a does not model the actual dynamics of a mortar firing. Instead, the effect is modeled by imparting an instantaneous velocity to the parachute, such that it travels away from the entry capsule at a given velocity. The parachute is normally held together by a bag (assumed massless) until the lines connecting the parachute to the vehicle become taut, at which point, the bag is discarded and the parachute begins to inflate. It is assumed that the inflation profile is a function of time only (Figure 15). The vehicle is initially traveling vertically downward with a velocity of 500 m/s and the parachute is ejected at 70 m/s upward relative to the entry capsule. The test was simulated in both POST II and in MATLAB.

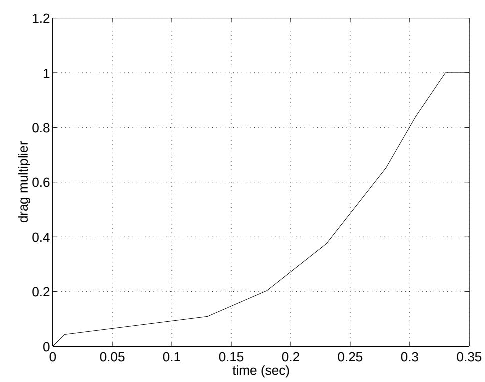
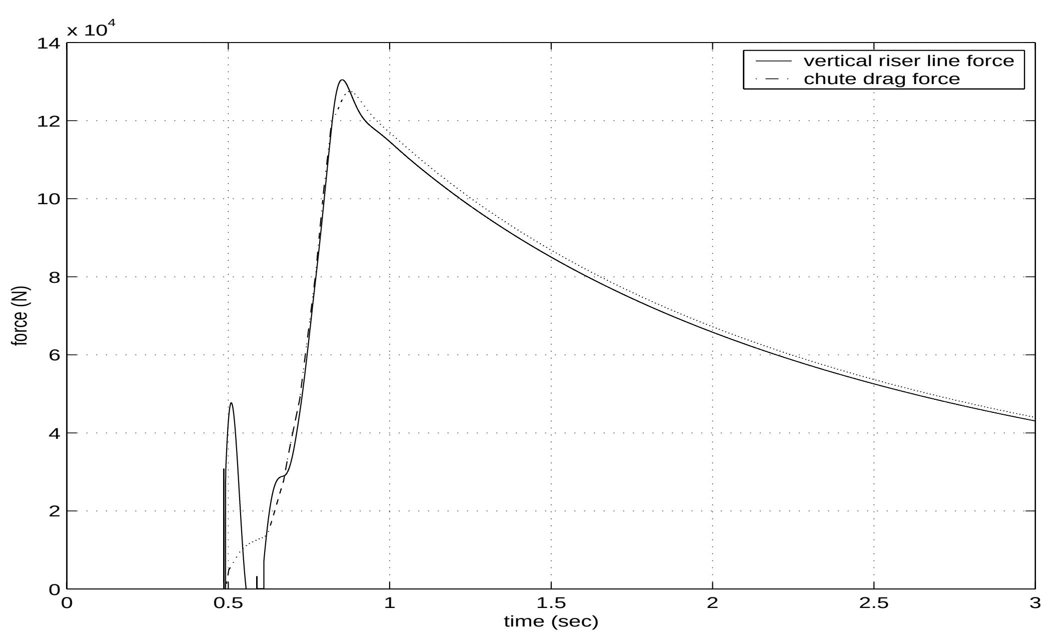


Figure 15 Parachute inflation profile

Figure 16 shows the force on the vertical riser, and also the drag force on the parachute. The force on the vertical riser is the summation of the parachute drag force and the inertial forces. Note that there are two peaks in the vertical riser force. Most of the time, the majority of the force experienced by the vertical riser is due to the parachute drag force; however the first peak is due to inertial forces. This peak, also called the “snatch load”, is caused when the parachute mass gets to the end of the line and is pulled back by the vertical riser, at which point is starts inflating. As the parachute inflates and the drag area increases, vertical riser force builds up again to another local maximum value called the “opening load”. The “opening load” is normally greater than the “snatch load” in opening of parachutes for systems of such configuration. The force then drops off as the vehicles slows down.

Figure 16 Forces on the parachute



The next two plots show the comparison of line forces from POST II versus MATLAB. Both plots demonstrate a very good comparison. However there are spikes in the percent difference plots. Both simulations use a 4th order Runge-Kutta with a 0.0001 second time step. These spikes are caused by the two simulations not being exactly synchronized; the time the lines move from slack to taut is off by a few time steps.

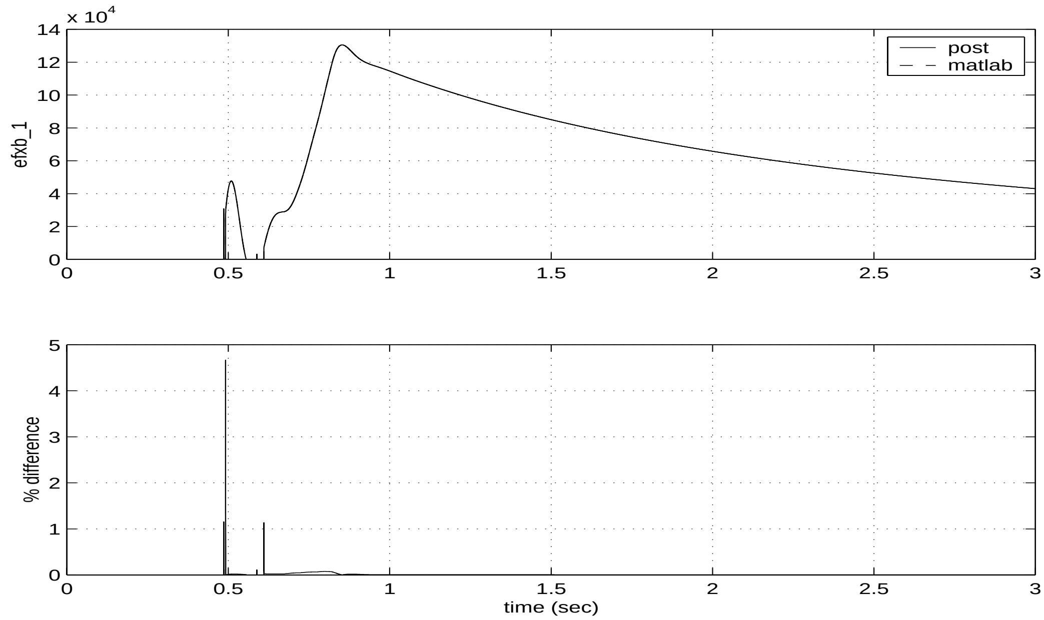


Figure 17 Vertical riser line force

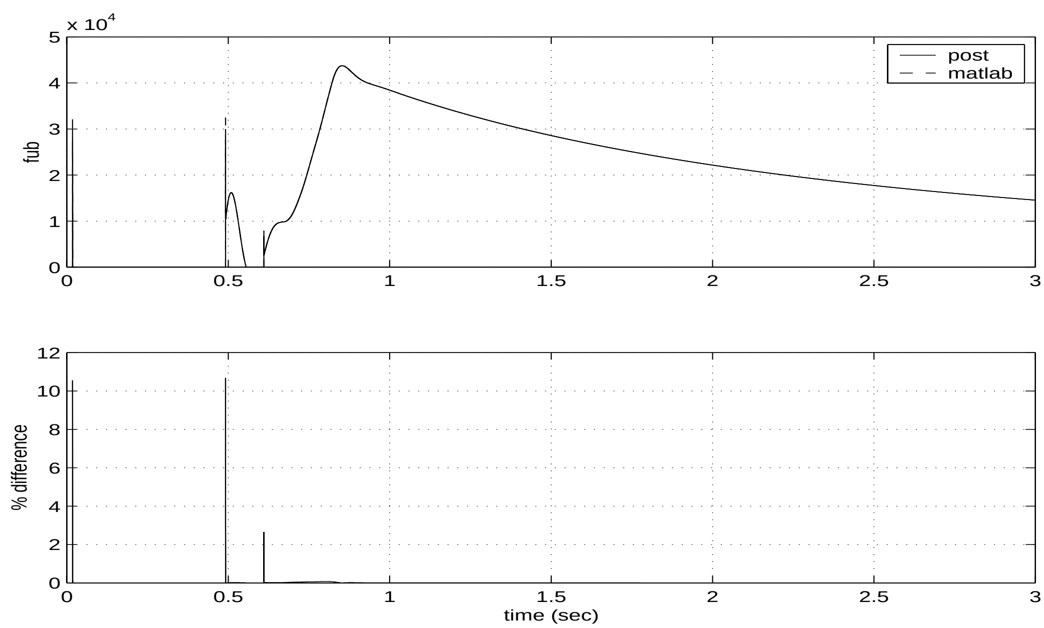


Figure 18 Upper Bridle line force

3.4. Run Time

Table 6 summarizes the effects of swivel mass and the integration time step on the simulation run times. All these are POST II runs utilizing the 4th order Runge-Kutta integrator. The swivel mass has a significant effect on the numerical stability of the runs and the integration step size that can be used. For a given swivel mass, there is an upper bound to step size beyond which the simulations fail. The effects of different line properties have also been recorded in this table. Nonlinear line properties tend to add numerical stability to these simulations, thus allowing us to use larger time steps resulting in shorter run times. Run times were clocked on the same processor (SGI MIPS R12000 400MHz processor). Note that the runs marked as "crash" indicate that the simulations did not reach completion. The runs marked as "erroneous" reached completions, but produced results that were clearly erroneous.

Table 6 Run time summary

integration step size (sec)	swivel mass (kg)	CPU run time (sec) using linear line properties	CPU run time (sec) using nonlinear line properties
0.0001	0.1539	325	291
0.0002	0.1539	160	164
0.0003	0.1539	erroneous	96
0.0004	0.1539	erroneous	erroneous
0.0005	0.1539	crash	crash
0.0010	0.5000	erroneous	33
0.0020	0.5000	erroneous	erroneous
0.0005	1.0000	57	58
0.0010	1.0000	29	29
0.0020	1.0000	erroneous	19
0.0030	1.0000	erroneous	erroneous
0.0050	1.0000	crash	crash

4. Conclusion

In order to validate the POST II parachute modeling, a series of test cases have been conceived. The level of complexity is incrementally increased for these test cases. The test cases are simulated using POST II and results are compared with simulations made with MATLAB. In this study, we simulated a three-body drop test case with a one-centimeter slack in the Vertical Riser. POST II and MATLAB simulations with the exact same input were made assuming the lines acted as linear, tension-only springs. The results of the simulations showed excellent agreement. The test was repeated using nonlinear springs based on Earth-bound Mars Viking test data. Again the agreement between the POST II and MATLAB simulations was excellent. A descent rate limiter (DRL) similar to that used on Mars Pathfinder and proposed for Mars Exploration Rover (MER) was modeled and tested in both simulations. The two simulations agreed very well. The slight differences observed are attributed to very small differences in timing while the vehicle is bouncing at the end of its tether. The final test case presented in this report is that of a parachute deployment. POST II and MATLAB simulations for this case agreed very well with each other. Again differences are attributed to small differences in the timing of bounces at the end of the tether. As the validation of the parachute model in POST II continues, all of the test cases above will be repeated using ADAMS. Also, additional tests will be performed comparing POST II against simulation tools other than MATLAB.

List of Acronyms

C	Line Damping coefficient
C_d	Drag coefficient
C_p	Center of pressure
DOF	Degree Of Freedom
DRL	Descend Rate Limiter
fpa	Flight Path Angle
IC	Initial Conditions
I_{xx}	Mass moment of inertial about body x-axis
I_{yy}	Mass moment of inertial about body y-axis
I_{zz}	Mass moment of inertial about body z-axis
K	Line stiffness coefficient
L0	Free length
MER	Mars Exploration Rover
POST	Program to Optimize Simulated Trajectories
S_{ref}	Reference drag area
TCM	Trajectory Correction Maneuver

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